# LOW ENERGY NUCLEAR BURSTS OF COSMIC RAYS AT SEA LEVEL

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Plate X

**ABSTRACT.** Measurement of cosmic ray burst in a thin-walled unshielded ionization chamber at Calcutta (sea level) is described. Bursts due to nuclear interactions are isolated from those due to airshowers by counter coincidence method. The integral size-frequency distribution of nuclear bursts is found to be capable of being represented by a power law with exponent $-3.4$.

The energy of an incident particle initiating a nuclear burst of a given size is evaluated with the help of the results of energy measurements of star prongs in photographic emulsion by other workers. The energy spectrum of cosmic ray nuclear-active particles producing bursts at sea level is then constructed and it is found that this can be represented by an empirical relation as: $N(E) = 240.E^{(.72-.89 \log E)}$ within the energy-range investigated viz., from 50 Mev to about 1 Bev.

## INTRODUCTION

Experiments on bursts in unshielded ionization chambers by various workers viz. Montgomery and Montgomery (1949), Carmichael (1948), (1955) and Bridge, Hazen, Rossi and Williams (1948) have established that such bursts are caused by two separate processes, i) extensive air showers and ii) nuclear interactions occurring in the wall or in the gas of the chamber. Different methods have been devised for isolating the latter from the former. Observation of bursts in unshielded chambers offers a convenient method for studying the low energy (below the energy at which meson production becomes important) nuclear interactions of cosmic rays with matter. This method has, indeed, been utilised by many workers, e.g., Coor (1951), Simpson *et al.* (1951), Rossi (1948), Montogomery *et al.* (1950), for the investigation of diverse characteristics such as the intensity variation with altitude and the absorption mean free path in air, the variation with latitude etc. of low energy nucleonic component of cosmic rays. The present experiment is designed to evaluate the energy distribution of cosmic ray particles producing bursts in an unshielded chamber at sea level.

## EXPERIMENTAL ARRANGEMENT

The apparatus consisted of a spherical ionization chamber made of steel, having a diameter of 10 cm. and wall thickness 3.2 mm. The gaseous volume of the chamber was 3.8 litres. Pure Argon (99% purity) was further purified by passing it thorugh a trap immersed in liquid oxygen. The chamber was filled with the gas to a pressure of about 20 atmospheres. The particulars of our ionization chamber are listed in Table I.

The chamber was used as a pulse ionization chamber employing positive-ion collection. The outer wall of the chamber was kept at a high potential of +1500 volts, while the central electrode was connected to an electrometer tube. In our experiment R.C.A. acorn tube type 959 was used instead of the conventional electrometer tube as suggested by Nielson (1947). The grid-leak of the tube was $1 \times 10^{11}$ ohms. The electrometer tube was followed by a d.c. amplifier and a short period galvanometer. The trace of the galvanometer spot was recorded photographically on a continuously moving 35 mm. ciné film by means of a camera driven by a synchronous motor. The record was projected on a graduated screen and the pulse heights were measured. A diagram of the ionization chamber is shown in Fig. 1 and the arrangement of the associated equipments is shown schematically in Fig. 2.

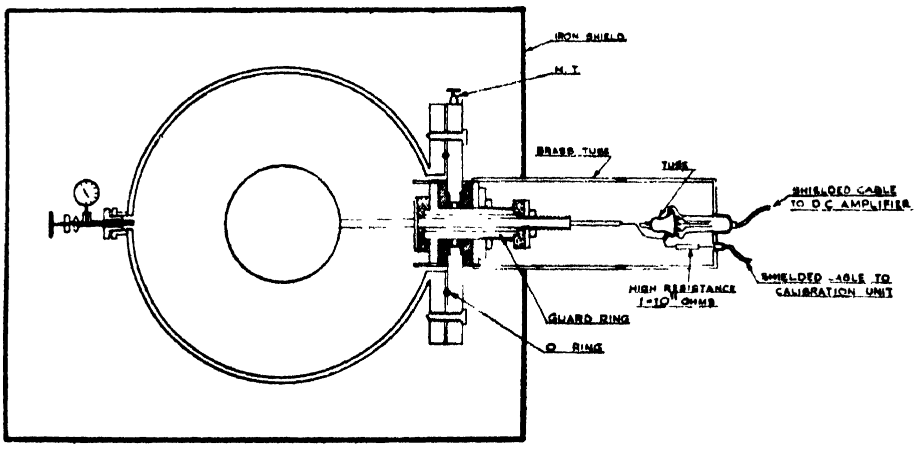


FIG 1. THE IONIZATION CHAMBER

INSULATORS POLYTHENE EBONITE

The ionization chamber was calibrated by applying a calibration pulse of known potential to the collecting electrode. The capacity of the chamber connected to the input of the d.c. amplifier was measured with the help of a quadrant electrometer and a standard capacitor. These values enabled us to estimate the burst size in terms of the number of ion pairs produced.

In order to isolate bursts due to nuclear interactions from those due to air-showers, the following method was employed. Two G-M counter trays, each consisting of two G-M counters connected in parallel were placed on either side of the ion chamber and in the same horizontal plane with it. The separation between a counter tray and the chamber was ½ metre. A coincidence between the discharges of the two counter trays was employed to ignite a lamp. This produced a 'dot' on the same photographic film on which the galvanometer trace was also recorded. The arrangement is shown in Fig. 2. A pulse in the ioni-

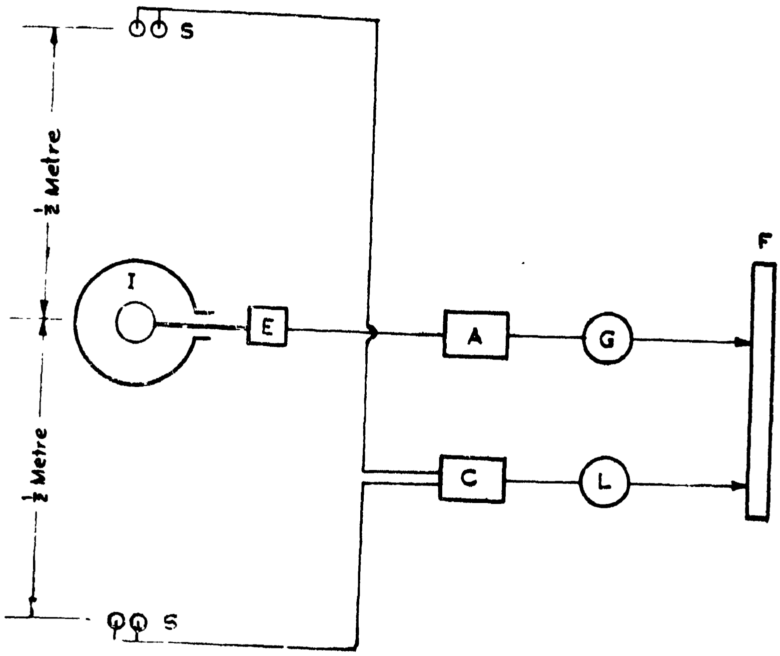


Fig. 2.

I—Ionization chamber
E—Electrometer tube
A—D. C. amplifier
G—Galvanometer
F—Film
S. S—Shower trays
C—Coincidence circuit
L—Lamp.

zation chamber coincident with a dot due to counter trays was recognised as a burst produced by air shower. A burst unaccompanied by such a simultaneous shower dot was taken to be a nuclear burst Facsimiles of record are shown in Fig. 3.

## RESULTS AND DISCUSSIONS

### (A) *Size-frequency distribution of nuclear bursts*

The pulse height pertaining to a burst as measured by projecting the film on a screen was converted to the corresponding potential change of the central electrode by comparing with the calibration pulse. From the change of potential

($V$) of the central electrode, the total number of ion pairs formed in the burst was obtained by the relation :

$$\text{Number of ion pairs} = \frac{Q}{e} = \frac{C.V}{e} . \qquad (1)$$

where $Q$ = the charge collected by the central electrode,

$C$ = the capacity of the chamber and its attachments,

and $e$ = the electronic charge.

The results of the measurements are represented by the integral size-frequency distribution of bursts shown in Fig. 4. The frequency of all bursts larger than a given size was plotted as a function of the size in curve $A$. The frequency of

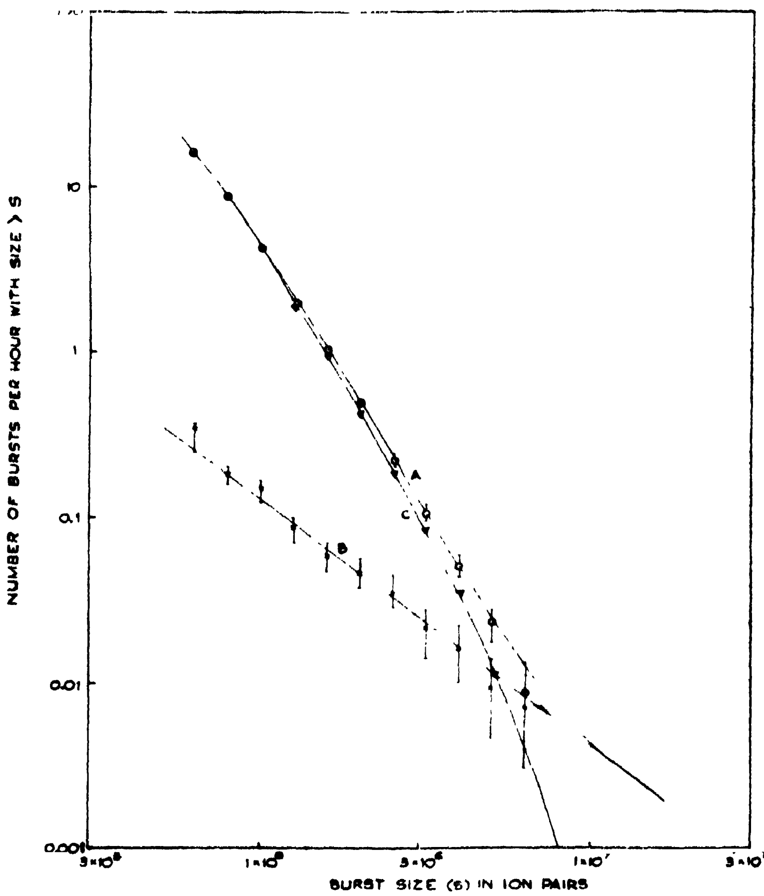


FIG. 4 INTEGRAL SIZE-FREQUENCY DISTRIBUTION OF BURSTS. (A) ALL BURSTS. (B) AIR SHOWERS (C) NUCLEAR BURSTS.

bursts due to air showers as obtained from the coincidence between the chamber and the shower trays was plotted against burst size in curve $B$. The frequency of air showers was then subtracted from the frequency of all bursts of the same size so that the remainder represented bursts due to nuclear interactions only.

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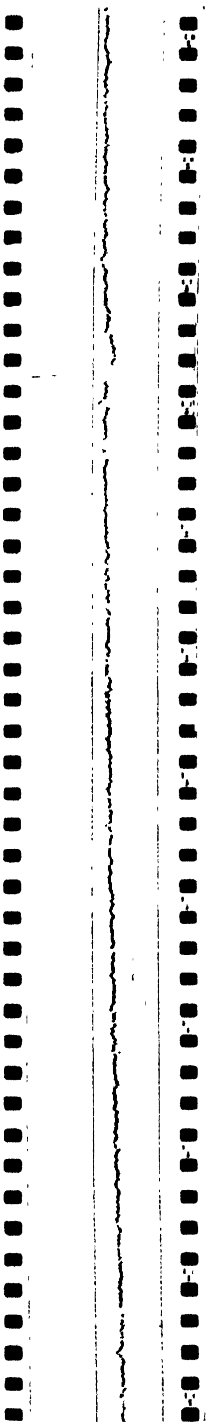
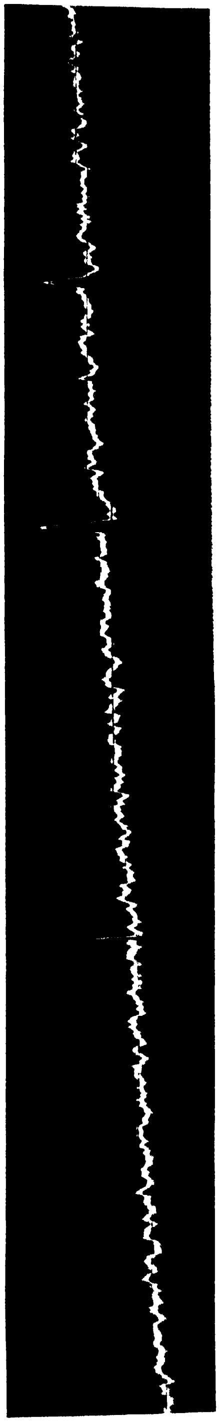
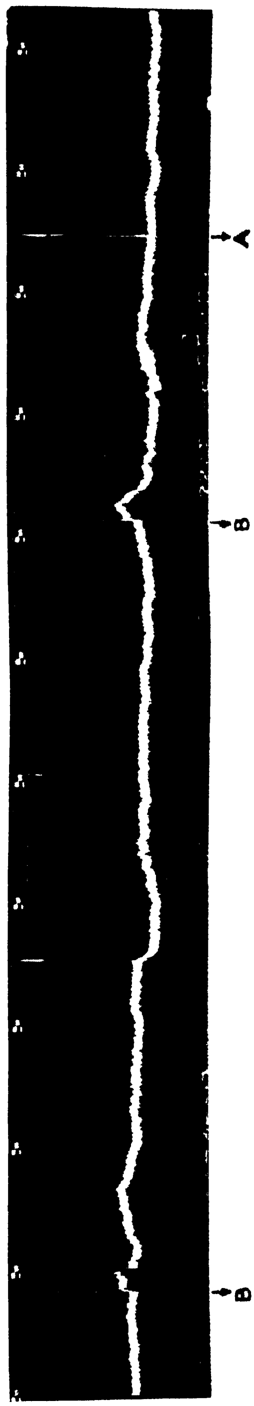


(a) Trace of a large burst as recorded by an Einthoven string galvanometer.



(b) A typical record of bursts using D'Arsonval galvanometer and fast film movement.




(c) A typical record of nuclear and air-shower bursts as recorded by a Ruhrstrat Galvanometer, with slower film movement

A = Burst due to air shower.

B = Nuclear bursts.

Fig. 3. Facsimiles of the record.

The size-frequency distribution of nuclear bursts, so obtained, is shown in curve $C$. This is also drawn separately in Fig. 5 (curve $A$).

The size-frequency curve shows that the frequency distribution of nuclear bursts can be approximately represented by a power law of the form :

$$N(>S) = A.S^{-\gamma} \qquad \dots \quad (2)$$

where $N(>S)$ represents the number (frequency) of bursts larger than the given size $S$,

$S$ is the burst size in ion pairs,

$A$ is a constant,

and the exponent $\gamma$ has the value $\gamma = -3.4$.

This power law is seen to be valid within the range of burst size from $8 \times 10^5$ to

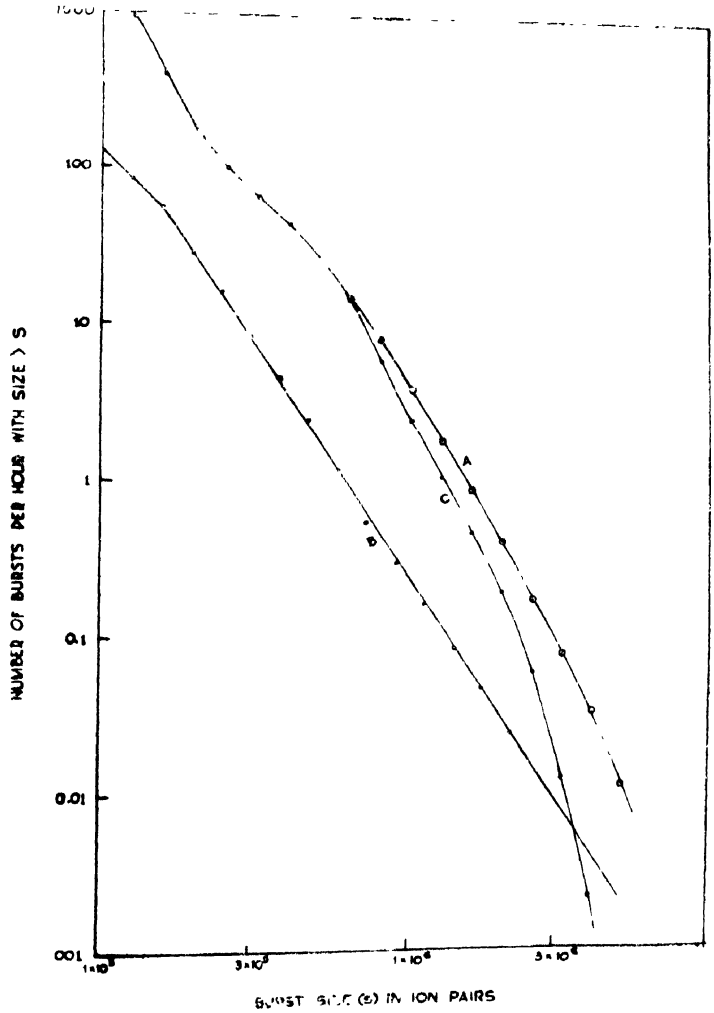



FIG 5. SIZE FREQUENCY DISTRIBUTION OF NUCLEAR BURSTS.

(A) - PRESENT AUTHORS (B) MONTGOMERY & MONTGOMERY (C) - CARMICHAEL

$3 \times 10^6$ ion pairs. For larger bursts, the frequency tends to decrease very rapidly with size.

In Fig. 5, are also plotted for comparison the size-frequency distribution curves of bursts in unshielded chamber obtained by Montgomery and Montgomery (1949) (curve B) and by Charmichael and Steljes (1955) (curve C). Certain relevant details regarding the apparatuses used by them are listed in Table I along with those of the present experiment.

TABLE I

| Author | Altitude of Observation | Chamber geometry | Dimensions (outer dia) | Chamber wall | Gaseous volume (litres) | Gas | Pressure (atm.) | Exponent of Power law |
|---|---|---|---|---|---|---|---|---|
| Montgomery and Montgomery | 3510m | Cylindrical | 3″ | 1/32″ brass | 1 | Argon | 4.8 | —3.2 |
| Carmichael and Steljes | Sea level | Spherical | 8″ | 1/16″ Steel | 4.4 | ,, | 50 | |
| Present authors | ,, | ,, | 8″ | 1/8″ Steel | 3.8 | ,, | 20 | 3.4 |

Montgomery and Montgomery's chamber was of smaller area and of smaller volume than ours. A change in these parameters would probably shift the curve vertically and laterally but the shape of the curve will not be altered. It is seen that Montgomery's distribution can be represented by a power law similar to equation (2) within a burst range from $2 \times 10^5$ to $2 \times 10^6$ ion pairs with an exponent $\gamma = -3.2$. The value of $\gamma$ obtained in the present experiment is seen to be in agreement with that of Montgomery and Montgomery.

Curve (C), Fig. 5 was drawn by subtracting the frequency of air showers from the corresponding frequency of all bursts from the data given in the paper of Carmichael and Steljes. It is seen that Carmichael's frequency distribution cannot be represented by a power law for any considerable range of burst size.

(B) *Energy spectrum of the bursts*

A nuclear burst is produced when a nuclear interaction occurs between an incident cosmic ray nuclear-active particle (N-component) and a nucleus of the chamber wall or of the chamber gas. The heavily ionizing particles released in the interaction produce the ionization pulse inside the gaseous volume of the chamber. The number of ion pairs produced in a burst is, therefore, a measure of the kinetic energy of all the secondary ionizing particles of the interaction and this energy can be evaluated from the relation :

$$E = \omega . S \qquad \ldots(3)$$

where $S$ is the size of the burst in ion pairs,

and $\omega$ is the energy required to create an ion pair, which is 25.4 ev for Argon. (Rutherford, Chadwick and Ellis, 1930).

But there are both charged and neutral particles (neutrons) among the secondaries of the interaction, and the chamber fails to record these neutrons. Hence the energy calculated from relation (3) has to be corrected for the contribution of neutrons to the total kinetic energy of the particles emitted in the burst process, which can be done approximately in the following way. Most of the ionizing secondaries of the interaction are protons, as revealed in the observation of cosmic ray stars in photographic emulsion. Also the majority of nuclear interactions occur within the wall of the chamber rather than within its gaseous volume. We may, then, assume the neutron/proton ratio among the emitted particles to be equal to 1.15 corresponding to the ratio of neutrons to protons in iron nucleus. The energy obtained from equation (3) is, therefore, multiplied by 2.15 to get the the total kinetic energy-release in a burst. The resulting number-energy distribution is plotted in Fig. 6.

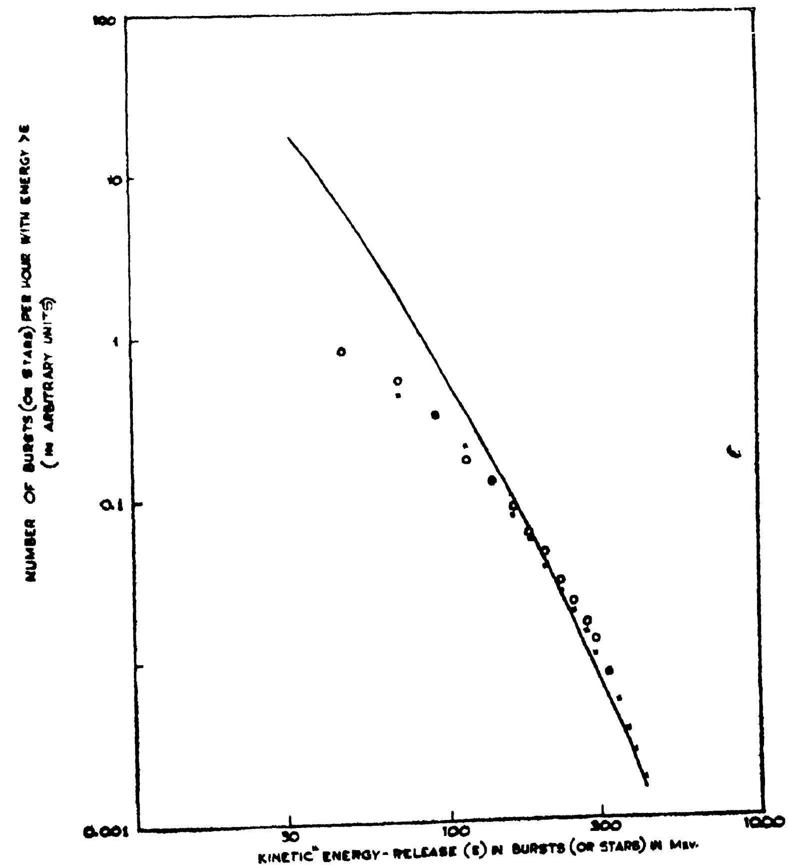



FIG. 6. NUMBER-ENERGY DISTRIBUTION OF BURSTS AND STARS.
—— PRESENT AUTHORS. • N. PAGE. × BROWN ET AL.

Since a nuclear burst is a process similar to that of formation of stars in photographic emulsion, we may compare the results of the present experiment with the observation of cosmic ray stars. The number of heavy tracks in a star is a measure of the energy released in the process. Majority of the heavy tracks are due to protons (Brown *et al.* 1949) and we may take the number of neutron/proton emitted in a star to be equal to 1.3 corresponding to the ratio of neutrons to protons in silver bromide. The number of heavy prongs in a star is then multiplied by 2.3 to account for the missing neutrons. Now we may assume that average kinetic energy of a secondary particle is 10 Mev (as observed from measurements of Brown *et al.*, the average kinetic energy of a dense track is 10 Mev). The total number of prongs in a star should then be further multiplied by 10 to obtain the energy-release in a star. The variation of number of stars with energy is deduced in the above way from the observations of cosmic ray stars at mountain altitude by Page (1950) and by Brown *et al.* (1949). These are also plotted in Fig. 6. From Brown's data, we have neglected stars accompanied by meson production (stars with thin tracks). In any case the omission did not appreciably affect the shape of the distribution. It may be seen that the distributions obtained from the measurements of both the authors are roughly in agreement with that obtained from the burst measurement of

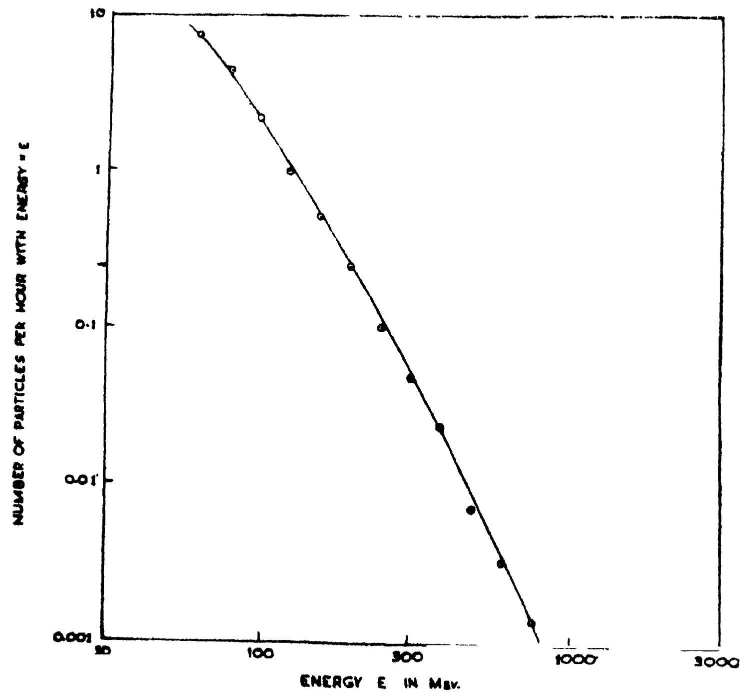



FIG. 7. ENERGY SPECTRUM OF BURST PRODUCING RADIATION

the present experiment, except in the region of low prong number. Taking into consideration the fact that the two measurements (that of bursts and of tars) were taken at different altitudes and by completely different techniques, the agreement in Fig. 6 perhaps indicates that our approximate method of evaluating the kinetic energy cannot be very much in error.

The burst energy shown in Fig. 6 gives the total kinetic energy of the secondary particles emitted in the nuclear process leading to a burst. But this is not the total energy that is transferred by the incident cosmic ray particle to the struck nucleus; because, in addition to the kinetic energy, binding energy has also to be supplied in the process of emission of a particle. Since there is no way of directly recording the number of particles producing the ionization of a burst in an ionization chamber, we assume as we have done in case of stars in emulsion, that average kinetic energy ($E$) of a particle emitted in a burst-process is 10 Mev. Then, the number of secondaries released in a burst is E/10, and assuming the binding energy per particle to be 8 Mev, we get the total energy (binding energy+kinetic energy) transferred in a burst to be eaual to 1.8E. Variation of number of bursts with this total energy is shown in Fig. 7. Assuming that the incident particle spends whole of its energy in producing the burst, Fig. 7 may be taken to represent the differential energy spectrum of the burst producing radiation. Within the energy-range under investigation, viz., from 50 Mev to about 1 Bev, this energy spectrum can be represented by a relation of the form :

$$N(E) = 240E^{(0.72-0.89\ \log E)} \tag{4}$$

where $N(E)$ is the number of particles with energy $E$ Mev.

In this analysis we have made two assumptions. Firstly, we have assumed all the secondaries of a burst (or a star) process are protons. Actually, besides protons there will be $\alpha$-particles also. The presence of $\alpha$-particles may affect our calculations in two ways. (i) We have taken the kinetic energy of all the neutrons to be 1.15 times the measured kinetic energy of all the secondaries. Strictly speaking, we should have taken 1.15 times the kinetic energy of the protons only. (ii) We have assumed the binding energy of all the secondaries to be 8 Mev. This might lead to an overestimate of the total energy because the binding energy of $\alpha$-particles is of smaller value (about 4 Mev). Since $\alpha$-particles constitute only a small fraction of the total number of secondaries (in Brown's measurements, the ratio of the number of $\alpha$-particles to the total number of charged secondaries varies from 0.15 to a maximum of 0.3 only), the error involved is not perhaps serious. Secondly, we have taken the average kinetic energy of all secondaries to be equal to 10 Mev. But, as Brown *et al.* (1949) have shown, the average kinetic energy of a grey track is much greater than this; a grey track corresponds to a fast proton of energy greater than 30 Mev. In a burst, a fast secondary proton corresponding to a grey track in stars will have a range larger than the average path length of a particle (13 cm.) inside the gaseous volume of the chamber. Because of its higher energy, the fast protons will have low specific ionization so that only a small fraction of its energy will be spent in producing ionization inside the chamber gas which may not be much different from 10 Mev. Thus we may conclude that in spite of the simplifications made, equation (4) (and the Fig. 7) represent the energy spectrum fairly well.

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